Consultative Committee for Space Data Systems

DRAFT RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

ORBIT DATA MESSAGES

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FOREWORD

(WHEN THIS RECOMMENDATION IS FINALIZED, IT WILL CONTAIN THE FOLLOWING FOREWORD:)

This document is a technical Recommendation for orbit data messages and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). The set of orbit data messages described in this Recommendation is the baseline concept for trajectory representation in data interchange applications that are cross-supported between Agencies of the CCSDS.

This Recommendation establishes a common framework and provides a common basis for the interchange of orbit data. It allows implementing organizations within each Agency to proceed coherently with the development of compatible derived standards for the flight and ground systems that are within their cognizance. Derived Agency standards may implement only a subset of the optional features allowed by the Recommendation and may incorporate features not addressed by this Recommendation.

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DOCUMENT CONTROL

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1 INTRODUCTION

1.1 PURPOSE

This Recommendation specifies a modern spacecraft ephemeris (trajectory) data standard for use in transferring spacecraft orbit information between Member Agencies. Such exchanges are required for (1) pre-flight planning for tracking or navigation support, (2) officially scheduling tracking support, (3) carrying out tracking operations (sometimes called metric predicts), and (4) orbit comparisons.

This Recommendation establishes two orbit data messages for use in ground-to-ground data interchange applications between Agencies of the CCSDS. This Recommendation does not address precision and accuracy of the derived spacecraft position and velocity.

This Recommendation includes sets of requirements and criteria that the message formats have been designed to meet. For exchanges where the existing requirements do not capture the needs of the participating agencies, the participating agencies may agree to use another mechanism for that particular exchange.

1.2 SCOPE AND APPLICABILITY

This Recommendation contains two orbit data messages designed for applications involving data interchange in space data systems. It does not prescribe which message to use for any particular application. The rationale behind the design of each message is described in annex A and may help the application engineer select a suitable message. Definition of the orbit accuracy underlying a particular orbit message is outside the scope of the Recommendation. Applicability information specific to each orbit data message format appears in sections 3 and 4.

1.3 REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Recommendation are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommendations.

[1] *Navigation Definitions and Conventions*. Report Concerning Space Data System Standards, CCSDS 500.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, June 2001.

[2] *Spacewarn Bulletin*. Greenbelt, MD, USA: World Data Center-A for Rockets and Satellites. [http://nssdc.gsfc.nasa.gov/spacewarn]

[3] *Standard Frequencies and Time Signals*. Volume 7 of *Recommendations and Reports of the CCIR: XVth Plenary Assembly*. Geneva: CCIR, 1982.

[4] *Information Technology—8-Bit Single-Byte Coded Graphic Character Sets—Part 1: Latin Alphabet No. 1*. International Standard, ISO/IEC 8859-1:1998. Geneva: ISO, 1998.

2 OVERVIEW

2.1 ORBIT DATA MESSAGES

Two CCSDS-recommended orbit data messages are described: the Orbit Parameter Message (OPM) and the Ephemeris Message (EPM). The two Recommended orbit data messages carry the object identification, the coordinate frame center, the coordinate frame identification, and the time system. The information required for each data message is listed in sections 3 and 4.

An OPM is an ASCII description of the position and velocity of an object for a specified epoch. This message is suited to inter-Agency exchanges that (1) involve automated interaction and/or human interaction and (2) do not require high-fidelity dynamic modeling.

An EPM is an ASCII table representation of the position and velocity history of an object over a specified time range. The Ephemeris Message is particularly suited to inter-agency exchanges that (1) involve automated interaction and (2) require high-fidelity dynamic modeling.

2.2 CATEGORIZING OF CCSDS ORBIT DATA MESSAGES

In this Recommendation, two orbit data messages are defined based on the two forms of interpretability of the message:

Interpretability Form 1: Orbit Parameter Propagation

The Orbit Parameter Message allows for the use of a propagation technique (analytical or numerical) to interpret the position and velocity at times different from the specified epoch. The OPM is fully self-contained; no additional information is required.

Interpretability Form 2: Tabular Interpolation

The Ephemeris Message format allows for the use of interpolation techniques to interpret the position and velocity at times different from the tabular epochs. The EPM is fully self-contained; no additional information is required.

3 ORBIT PARAMETER MESSAGE (OPM)

3.1 OVERVIEW

3.1.1 Orbit information may be exchanged between two participants by sending a state vector (see reference [1]) for a specified epoch within an Orbit Parameter Message (OPM).

3.1.2 In this case, the message receiver site must have an orbit propagator available that is able to propagate the OPM state vector to compute the orbit at desired epochs. For this propagation, additional ancillary information (spacecraft properties such as mass, area, and maneuver planning data, if applicable) is to be included with the message.

3.1.3 Thus, the use of the Orbit Parameter Message (OPM) is applicable under the following conditions:

- an orbit propagator is run at the receiver's site;
- the receiver's modeling of gravitational forces, solar radiation pressure, atmospheric drag and thrust phases (see reference [1]) fulfill accuracy requirements established between the agencies.

3.2 OPM REQUIREMENTS

3.2.1 GENERAL

The OPM shall be easily readable by both humans and computers.

3.2.2 OPM FILE

3.2.2.1 Each OPM file shall contain all obligatory fields (see table 3-1).

3.2.2.2 The particular file naming specification shall be agreed to on a case-by-case basis between the participating Agencies.

3.2.2.3 The OPM shall be a text file, consisting of orbit data for a single object.

3.2.3 LINES

3.2.3.1 The OPM line length must not exceed 80 characters, not including end-of-line characters.

3.2.3.2 Only printable ASCII characters and blanks may be used. Control characters (such as TAB, etc.) are not allowed.

3.2.3.3 The first non-blank line in the file must contain the CCSDS version specification.

3.2.3.4 Blank lines may occur at any position of the file (blank lines are ignored).

3.2.3.5 Optional comment lines may occur at any position in the file after the header.

3.2.3.6 The designator for a comment line must be given at the beginning of every comment line.

3.2.3.7 The native end-of-line control sequence is used for line termination.

3.2.3.8 All data lines shall use 'keyword = value' syntax.

3.2.3.9 It is recommended that white space (blanks) be inserted on both sides of the equal sign, but this is not a requirement.

3.2.4 KEYWORDS

3.2.4.1 Only those keywords shown in table 3-1 are allowed.

3.2.4.2 Keywords are all uppercase and do not contain blanks.

3.2.4.3 The order of the occurrence of obligatory and optional items is fixed as shown in table 3-1. Exceptions are blank or comment lines.

3.2.5 VALUES

3.2.5.1 In the values associated with keywords, individual blanks are retained (are significant), but multiple blanks are equivalent to a single blank. Underscores are equivalent to a single blank.

3.2.5.2 For all fields, it is recommended that values be expressed in either fixed or floating point notation.[1]

3.2.5.3 Value fields may be constructed using mixed case: case is not significant.

3.2.5.4 There are no default values assumed for keywords.

3.2.5.5 A valid value for each item must be specified in each occurrence of a keyword.

3.2.5.6 Trailing blanks are not significant.

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[1] For floating point notation, agencies need to ensure that (a) the decimal point location, (b) the limit on the number of digits in the mantissa, (c) the range of digits in the exponent, (d) the limit on the magnitude of the number, and (e) the allowable character to denote the notation (i.e. 'D,' 'd,' 'E,' 'e,' etc.) are consistent with the capabilities of both agencies.

3.2.6 UNITS

3.2.6.1 Only units specified in table 3-1 are allowed.

3.2.6.2 For clarity, units can be included as ASCII text after the keyword values, but they do not supercede the units specified in table 3-1.

3.3 HEADER FIELD

3.3.1 The header must be the first non-blank line in the file.

3.3.2 The header shall provide a CCSDS Orbit Data Standard version number that identifies the format version in a ‘keyword = value’ format; this is included to anticipate future changes.

NOTE – The version number associated with the current issue of this Recommendation is ‘1.0’.

3.4 OPM KEYWORD SET

3.4.1 The keywords used in an OPM file shall be those given in table 3-1.

3.4.2 Keywords identified as ‘Obligatory’ must appear in every OPM file.

NOTE – Table 3-1 specifies for each item (1) its required sequence of occurrence in the OPM file, (2) the keyword to be used, (3) a short description, (4) the required unit, if applicable, and (5) whether or not the item is required or optional.

Table 3-1: OPM Keyword Descriptions

Keyword	Description	Units	Obligatory
General Information			
CREATION_DATE	File Creation Date	N/A	Yes
OBJECT_NAME	Object Name	N/A	Yes
OBJECT_ID	Object International ID Specification	N/A	Yes
CENTER_NAME	Coordinate System Center	N/A	Yes
REF_FRAME	Coordinate System	N/A	Yes
TIME_SYSTEM	Time System Representation	N/A	Yes
EPOCH	State Vector Epoch	N/A	Yes
State Vector Components in the Specified Coordinate System			
X	Position vector X-component	KM	Yes
Y	Position vector Y-component	KM	Yes
Z	Position vector Z-component	KM	Yes
X_DOT	Velocity vector X-component	KM/S	Yes
Y_DOT	Velocity vector Y-component	KM/S	Yes
Z_DOT	Velocity vector Z-component	KM/S	Yes
Keplerian Elements in the Specified Coordinate System (none or all parameters of this block are to be given)			
SEMI_MAJOR_AXIS	Semi-major axis	KM	No
ECCENTRICITY	Eccentricity	N/A	No
INCLINATION	Inclination	DEG	No
RA_OF_ASC_NODE	Right Ascension of ascending node	DEG	No
ARG_OF_PERICENTER	Argument of pericenter	DEG	No
TRUE_ANOMALY	True anomaly	DEG	No
GM	Gravitational Coefficient	KM^3/S^2	No
Spacecraft Parameters			
MASS	S/C Mass at Epoch of ignition	KG	Yes
SOLAR_RAD_AREA	Solar Radiation Pressure Area (A_R).	M^2	Yes
SOLAR_RAD_COEFF	Solar Radiation Pressure Coefficient (C_R).	N/A	Yes
DRAG_AREA	Drag Area (A_D).	M^2	Yes
DRAG_COEFF	Drag Coefficient (C_D).	N/A	Yes
Maneuver Parameters (Repeat for each maneuver (none or all parameters of this block are to be given))			
MAN_EPOCH_IGNITION	Epoch of ignition	N/A	No
MAN_DURATION	Maneuver duration	S	No
MAN_MASS_FLOW_RATE	Mass flow rate	KG/S	No
MAN_REF_FRAME	Coordinate system for velocity increment vector	N/A	No
MAN_DV_1	1st component of the velocity increment	KM/S	No
MAN_DV_2	2nd component of the velocity increment	KM/S	No
MAN_DV_3	3rd component of the velocity increment	KM/S	No
Comments (allowed everywhere in the message after the OPM version no.)			
COMMENT	Each comment line has to begin with this keyword.	N/A	No

3.5 SPECIFICATION OF OPM KEYWORD VALUES

3.5.1 GENERAL INFORMATION KEYWORDS

– ***File Creation Date (CREATION_DATE):*** Time that file was created.

– ***Name of Spacecraft (OBJECT_NAME)***: The spacecraft name, which shall be specified before each mission (e.g., STS 105, ASTRA 1B, CLUSTER 2/FM6 etc.).

– ***Spacecraft ID (OBJECT_ID)***: International spacecraft designator (as published in the SPACEWARN Bulletin (reference [2])). Valid values have the format *YYYY-NNN-P{PP}*, where:

YYYY	=	Year of launch.
NNN	=	Three digit serial number of launch in year YYYY (with leading zeros).
P{PP}	=	At least one capital letter for the identification of the part brought into space by the launch.

– ***Center of Coordinate Frame (CENTER_NAME)***: The center of the reference frame in which the state vector or Keplerian elements are given (e.g., EARTH, SOLAR SYSTEM BARYCENTER, MARS, etc.).

– ***Coordinate Frame (REF_FRAME)***: The reference frame in which the state vector or Keplerian elements are given. The allowable values are

- ICRF,
- ITRF-93,
- TOD 1950 (True Equator of Date of 1950.0),
- TOD 2000 (True Equator of Date of 2000.0),
- EME 1950 (Earth Mean Equator of 1950.0), and
- EME 2000 (Earth Mean Equator of 2000.0).

– ***Time System (TIME_SYSTEM)***: The time system representation in which epochs are given. The allowable values are

- TDB,
- GPS,
- TAI,
- TCB,
- TT, and
- UTC.

– ***Epoch of Orbit Data (EPOCH)***: Epoch of the state vector (and optional Keplerian elements) given in the message. Can be given in (1) ISO/CCSDS ASCII formats and (2) Julian Date strings. For example:

  ISO Formats:[1]
  1996-12-18T14:28:15.1172
  1996-277T07:22:54

  Julian Date Strings:
  2451534.29812

3.5.2 STATE VECTOR KEYWORDS

State vector keywords shall be used to specify position (**X, Y, Z**) and velocity (**X_DOT, Y_DOT, Z_DOT**) components at the given epoch in the units km and km/s, respectively.

3.5.3 KEPLERIAN ELEMENTS AND GRAVITATIONAL COEFFICIENT KEYWORDS

3.5.3.1 If applicable (in some cases, e.g., $i = 0°$, $e \geq 1$, the application of Keplerian elements does not make sense), the Keplerian elements can be included in the OPM in addition to the state vector to aid the message recipient in performing a consistency check.

3.5.3.2 The use of Keplerian elements for consistency checking is to be arranged within an ICD.

3.5.3.3 The **GM** value (Gravitational Coefficient = Gravitational Constant × Central Mass) used by the transmitter of the message for the conversion of state vector to Keplerian elements (or vice versa) must also be given. The required units for GM are km^3/s^2.

3.5.3.4 If included, this block of must be listed in its entirety.

3.5.4 SPACECRAFT PARAMETER KEYWORDS

Spacecraft parameter keywords shall be used to specify the following:

– ***Spacecraft Mass (MASS)***: The spacecraft mass at the specified epoch, given in kg.

– ***Solar Radiation Pressure (SOLAR_RAD_AREA, SOLAR_RAD_COEFF)***: The values for parameters A_R and C_R may be given for modeling the solar radiation

[1] The two ASCII time code variations (day of month and day of year) include the most widely used human-readable presentations. Both variations are subsets of ISO 8601 (*Data Elements and Interchange Formats—Information Interchange—Representation of Dates and Times*, International Standard, ISO 8601:2000, 2nd ed., Geneva: ISO, 2000).

pressure (see reference [1]). If $C_R = 0$ is set, no solar radiation pressure shall be taken into account.

– ***Atmospheric Drag Parameters***: The values for parameters A_D and C_D may be given for modeling the atmospheric drag (see reference [1]). If $C_D = 0$ is set, no atmospheric drag shall be taken into account.

3.5.5 MANEUVER KEYWORDS

3.5.5.1 Parameters for thrust phases may be given optionally for the computation of the trajectory during or after maneuver execution (see reference [1] for the simplified modeling of such maneuvers).

3.5.5.2 If included in an OPM, the following set of maneuver parameter keywords shall be repeated for each maneuver:

– ***MAN_EPOCH_IGNITION***: The epoch of start of the thrust phase is given in the same time system specified with keyword TIME_SYSTEM.

– ***MAN_DURATION***: The duration of the thrust phase is given in seconds (s). For impulsive maneuvers, the duration is set to zero.

– ***MAN_MASS_FLOW_RATE***: The average mass flow rate of the propulsion system during that maneuver, given in kg/s. For impulsive maneuvers, this parameter does not have any relevance and may be set to zero.

– ***MAN_REF_FRAME***: The coordinate system in which the velocity increment vector components are given. Values for this keyword include (1) those for keyword **REF_FRAME** and (2) the RTN reference frame, which is more suitable for the description of the velocity increment vector. The RTN reference frame is similar to the HCL (height, cross-track, along-track) coordinate system.

RTN Reference Frame:

R	=	Radial component (in direction of the position vector); $\hat{R} = \vec{r} / \lvert\vec{r}\rvert$
T	=	Along-Track (tangential) component (in the orbital plane perpendicular to the radial direction); $\hat{T} = \hat{N} \times \hat{R}$
N	=	Cross-Track (normal) component (perpendicular to the orbital plane in the direction of the angular momentum vector); $\hat{N} = \vec{r}\times\vec{v} / \lvert\vec{r}\times\vec{v}\rvert$

– ***MAN_DV_1, MAN_DV_2, MAN_DV_3***: The components of the velocity increment vector (km/s) are given in the above-specified reference frame.

3.6 CCSDS ORBIT PARAMETER MESSAGE (OPM) EXAMPLES

3.6.1 COMMENT FORMAT

3.6.1.1 All comment lines shall begin with the 'COMMENT' token. This token must appear on every comment line, not just the first such line.

3.6.1.2 White space is retained (is significant) in comments and shall separate the 'COMMENT' token from the text of the comment.

3.6.2 RECOMMENDED COMMENTS

NOTE – Comments are intended to help describe dynamical events or other pertinent information associated with the ephemeris data. This additional information is intended to aid in consistency checks and elaboration where needed, yet is not officially required for successful processing of a file.

There are certain pieces of information that provide clarity and remove ambiguity about the interpretation of the information in a file, yet are not standardized so as to fit cleanly into the 'keyword = value' paradigm. Rather than force the information to fit into a space limited to 80 characters, it is recommended to put the following information into comments, and to use the ICD to provide further specifications:

– Source or message originator (e.g. CNES, ESOC, GSFC, GSOC, JPL, NASDA, etc.):

```
COMMENT Source: File created by JPL Multi-Mission Navigation Team as part
COMMENT of Launch Operations Readiness Test held on 20 April 2001.
```

– Natural Body Ephemeris Information: When the Earth is not the center of motion, the ephemerides of the planets, satellites, asteroids, and/or comets (including associated constants) consistent with the ephemeris file are to be identified so that the recipient can, in a consistent manner, make computations involving other centers:

```
COMMENT Ephemerides: Created using small-body ephemeris file for 1 Ceres
COMMENT (SB-A1-23).  Based on latest orbit solution which includes observations
COMMENT through 2000-May-15; relative to planetary ephemeris DE-0405.
```

3.6.3 OPM EXAMPLES

Figures 3-1 and 3-2 are examples of Orbit Parameter Messages.

```
CCSDS_OPM_VERS = 1.0
COMMENT GEOCENTRIC, CARTESIAN, EARTH FIXED
OBJECT_NAME = GODZILLA 5
CENTER_NAME = EARTH
REF_FRAME = IRTF
TIME_SYSTEM = UTC
COMMENT OBJECT_ID: 1998-057-A
COMMENT $ITIM= 1998 OCT 09 22:26:18.40000000, $ original launch time 21:58
COMMENT $ITIM= 1998 OCT 09 22:23:18.40000000, $ reflects -3mn shift 21:55
COMMENT $ITIM= 1998 OCT 09 22:28:18.40000000, $ reflects +5mn shift 22:00
COMMENT $ITIM= 1998 OCT 09 22:58:18.40000000, $ reflects+30mn shift 22:30
COMMENT $ITIM= 1998 OCT 09 23:18:18.40000000, $ reflects+20mn shift 22:50
EPOCH = 1996-12-18T14:28:15.1172
X = 6503.514000
Y = 1239.647000
Z = -717.490000
X_DOT = -0.873160
Y_DOT = 8.740420
Z_DOT = -4.191076
MASS = 3000.000000
SOLAR_RAD_AREA = 18.770000
SOLAR_RAD_COEFF = 1.000000
DRAG_AREA = 18.770000
DRAG_COEFF = 2.500000
```

Figure 3-1: OPM File Example Using Comments to Denote Updates

```
CCSDS_OPM_VERS = 1.0

OBJECT_NAME       =  GODZILLA W5
OBJECT_ID         =  2000-028-A

COMMENT  Current orbit and maneuver planning data
COMMENT  Source: GSOC
COMMENT  Object_ID: 2000-028-A

CENTER_NAME       =  EARTH
REF_FRAME         =  TOD
TIME_SYSTEM       =  UTC
EPOCH             =  1996-12-18T14:28:15.1172

COMMENT  State Vector

X                 =    6655.9942  KM
Y                 =  -40218.5751  KM
Z                 =     -82.9177  KM
X_DOT             =   3.11548208  KM/S
Y_DOT             =   0.47042605  KM/S
Z_DOT             =  -0.00101495  KM/S

COMMENT  Keplerian elements
SEMI_MAJOR_AXIS   =   41399.5123  KM
ECCENTRICITY      =  0.020842611
INCLINATION       =     0.117746  DEG
RA_OF_ASC_NODE    =    17.604721  DEG
ARG_OF_PERICENTER =   218.242943  DEG
TRUE_ANOMALY      =    41.922339  DEG
GM                =  398600.4415  KM**3/S**2

COMMENT  Spacecraft parameters
MASS              =  1913.000  KG
SOLAR_RAD_AREA    =    10.000  M**2
SOLAR_RAD_COEFF   =    82.682
DRAG_AREA         =    10.000  M**2
DRAG_COEFF        =     2.981

COMMENT  2 planned maneuvers

COMMENT  First maneuver: non-impulsive, thrust direction fixed in
inertial
COMMENT  coordinate frame
EPOCH_IGNITION    =   1996-12-18T09:28:15
DURATION_MAN      =   132.60  S
MASS_FLOW_RATE    =   0.1389  KG/S
REF_FRAME_MAN     =   TOD
DV_1_MAN          =  -0.02325700  KM/S
DV_2_MAN          =   0.01683160  KM/S
DV_3_MAN          =  -0.00893444  KM/S

COMMENT  Second maneuver: impulsive, thrust direction fixed in RTN frame
EPOCH_IGNITION    =   1996-12-18T18:45:18
DURATION_MAN      =     0.00  S
MASS_FLOW_RATE    =   0.0000  KG/S
REF_FRAME_MAN     =   RTN
DV_1_MAN          =   0.00101500  KM/S
DV_2_MAN          =  -0.00187300  KM/S
DV_3_MAN          =   0.00000000  KM/S
```

Figure 3-2: OPM File Example with Optional Keplerian Elements and Two Maneuvers

4 EPHEMERIS MESSAGE (EPM)

4.1 OVERVIEW

The Recommendation calls for an ephemeris message (EPM) that can be represented as a combination of (1) a header, (2) metadata (data about data), (3) comments (explanatory information), and (4) ephemeris data.

4.2 EPM REQUIREMENTS

NOTE – In this subsection, a number of formatting, syntax, and contents rules for the EPM are provided as part of this recommendation. The design is intended to find an appropriate balance between simplicity (for both producers and consumers) and safety.

4.2.1 EPM FILE

4.2.1.1 Each EPM file shall contain all obligatory fields (see table 4-1).

4.2.1.2 The particular file naming specification shall be agreed to on a case-by-case basis between the participating Agencies.

4.2.1.3 The EPM shall be a text file, consisting of orbit data for a single object.

4.2.2 LINES

4.2.2.1 The EPM line length must not exceed 255 characters, not including end-of-line characters.

4.2.2.2 Only printable ASCII characters and blanks may be used. Control characters (such as TAB, etc.) are not allowed.

4.2.2.3 The first non-blank line in the file must contain the CCSDS version specification.

NOTE – The version number associated with the current issue of this Recommendation is ‘1.0’.

4.2.2.4 Blank lines are allowed at any position of the file, including within a metadata block or comment (blank lines are ignored).

4.2.2.5 Optional comment lines may occur at any position of the file after the header, outside of a metadata block.

4.2.2.6 The designator for a comment line must be given at the beginning of every comment line.

4.2.2.7 The native end-of-line control sequence is used for line termination.

4.2.2.8 All data lines shall use 'keyword = value' syntax.

4.2.2.9 It is recommended that white space (blanks) be inserted on both sides of the equal sign, but this is not a requirement.

4.2.3 KEYWORDS

4.2.3.1 Only those keywords shown in table 4-1 are allowed.

4.2.3.2 Keywords are all uppercase and do not contain blanks.

4.2.3.3 Keywords are not order-dependent in an EPM.

4.2.4 VALUES

4.2.4.1 In the values associated with keywords, individual blanks are retained (are significant) but multiple blanks are equivalent to a single blank. Underscores are equivalent to a single blank.

4.2.4.2 For all fields, it is recommended that values be expressed in either fixed or floating point notation.[1]

4.2.4.3 Value fields may be constructed using mixed case: case is not significant.

4.2.4.4 There are no default values assumed for metadata items.

4.2.4.5 A valid value for each item must be specified in each occurrence of the metadata block.

4.2.4.6 Trailing blanks are not significant.

4.2.5 UNITS

4.2.5.1 Units for position and velocity components are in km and km/s, respectively.

4.2.5.2 For clarity, units can be included as ASCII text in the comments, but they do not supercede the units specified in 4.2.5.1.

---

[1] For floating point notation, agencies need to ensure that (a) the decimal point location, (b) the limit on the number of digits in the mantissa, (c) the range of digits in the exponent, (d) the limit on the magnitude of the number, and (e) the allowable character to denote the notation (i.e. 'D,' 'd,' 'E,' 'e,' etc.) are consistent with the capabilities of both agencies.

4.3 HEADER FIELD

4.3.1 The header must be the first non-blank line in the file.

4.3.2 The header shall provide a CCSDS Orbit Data Standard version number that identifies the format version in a 'keyword = value' format; this is included to anticipate future changes.

4.4 EPM KEYWORD SET

4.4.1 The metadata provide the key information needed by the customer of the product to interpret the spacecraft ephemeris data.

4.4.2 Metadata shall be expressed using the 'keyword=value' notation given in table 4-1.

NOTE – Table 4-1 specifies for each item (1) the keyword to be used, (2) a short description, and (3) example values. The table shows the full set of metadata; only those keywords shown in the table are allowed. For some keywords there are no definitive lists of authorized values maintained by a control authority; the recommended references are the best known candidates for authorized values to date.

4.4.3 The following are the keyword-value notation recommendations:

Table 4-1: EPM Metadata Keywords

Keywords	Content	Examples of Values
OBJECT_NAME	There is no CCSDS-based restriction on the value for this keyword, but it is recommended to use names from the NASA SPACEWARN Bulletin (reference [2]), which include Object name, NORAD catalog number, or international designator of the participant.	Name / Catalog Number / International Designator **EUTELSAT W1** 26487 2000-052A **MARS PATHFINDER** 24667 1996-068A **STS 106** 26489 2000-053A **NAVSTAR 24** 21890 1992-009A **NEAR** 23784 1996-008A
OBJECT_ID	International spacecraft designator (as published in the SPACEWARN Bulletin (reference [2])). Valid values have the format *YYYY-NNN-P{PP}*, where: YYYY = Year of launch. NNN = Three digit serial number of launch in year YYYY (with leading zeros). P{PP} = At least one capital letter for the identification of the part brought into space by the launch.	Name / Catalog Number / International Designator EUTELSAT W1 26487 **2000-052A** MARS PATHFINDER 24667 **1996-068A** STS 106 26489 **2000-053A** NAVSTAR 24 21890 **1992-009A** NEAR 23784 **1996-008A**
CENTER_NAME	Origin of reference frame, which can be a natural solar system body (planets, asteroids, comets, and natural satellites), including any planet barycenter or the solar system barycenter, or another spacecraft (in this case the value for 'CENTER_NAME' is subject to the same rules as for 'OBJECT_NAME'). There is no CCSDS-based restriction on the value for this keyword, but for natural bodies it is recommended to use names from the NASA/JPL Solar System Dynamics Group (at http://ssd.jpl.nasa.gov).	EARTH EARTH BARYCENTER MOON SOLAR SYSTEM BARYCENTER SUN JUPITER BARYCENTER STS 106 EROS
REF_FRAME	Time representation. It is recommended to use names from *Navigation Definitions and Conventions* (reference [1]).	Value ICRF ITRF-93 TOD 1950 (True Equator of Date of 1950.0) TOD 2000 (True Equator of Date of 2000.0) EME 1950 (Earth Mean Equator of 1950.0) EME 2000 (Earth Mean Equator of 2000.0)
TIME_SYSTEM	Time system. It is recommended to use names from *Navigation Definitions and Conventions* (reference [1]).	TDB, GPS, TAI, TCB, TT, UTC
META_START, META_STOP	The EPM message contains both metadata and ephemeris data; these keywords are used to delineate the metadata blocks within the message. Metadata are provided in a block, surrounded by 'META_START' and 'META_STOP' markers to facilitate file parsing. These keywords must appear on lines by themselves.	See the Examples in 4.8.
START_TIME, STOP_TIME	Start and end of time span covered by ephemeris data immediately following the metadata block, respectively. Can be given in (1) ISO/CCSDS ASCII formats and (2) Julian Date strings. The START_TIME time tag at a new block of ephemeris data must be equal to or greater than the STOP_TIME time tag of the previous block.	ISO Formats:[1] 1996-12-18T14:28:15.1172 1996-277T07:22:54 Julian Date Strings: 2451534.29812
CREATION_DATE	Time that file was created.	Same as those for START_TIME,STOP_TIME.

[1] The two ASCII time code variations (day of month and day of year) include the most widely used human-readable presentations. Both variations are subsets of ISO 8601 (*Data Elements and Interchange Formats—Information Interchange—Representation of Dates and Times*, International Standard, ISO 8601:2000, 2nd ed., Geneva: ISO, 2000).

4.5 COMMENTS

4.5.1 COMMENT FORMAT

4.5.1.1 All comment lines shall begin with the '`COMMENT`' token. This token must appear on every comment line, not just the first such line.

4.5.1.2 White space is retained (is significant) in comments and shall separate the '`COMMENT`' token from the text of the comment.

4.5.1.3 Comment lines may not appear within a metadata block.

4.5.2 RECOMMENDED COMMENTS

NOTE – Comments are intended to help describe dynamical events or other pertinent information associated with the ephemeris data. This additional information is intended to aid in consistency checks and elaboration where needed, yet is not officially required for successful processing of a file.

There are certain pieces of information that provide clarity and remove ambiguity about the interpretation of the information in a file, yet are not standardized so as to fit cleanly into the 'keyword = value' paradigm. Rather than force the information to fit into a space limited to 255 characters, it is recommended to put the following information into comments, and to use the ICD to provide further specifications:

– Source or message originator (e.g. CNES, ESOC, GSFC, GSOC, JPL, NASDA, etc.):

```
COMMENT Source: File created by JPL Multi-Mission Navigation Team as part
COMMENT of Launch Operations Readiness Test held on 20 April 2001.
```

– Natural Body Ephemeris Information: When the Earth is not the center of motion, the ephemerides of the planets, satellites, asteroids, and/or comets (including associated constants) consistent with the ephemeris file is to be identified so that the recipient can, in a consistent manner, make computations involving other centers:

```
COMMENT Ephemerides: Created using small-body ephemeris file for 1 Ceres
COMMENT (SB-A1-23).  Based on latest orbit solution which includes observations
COMMENT through 2000-May-15; relative to planetary ephemeris DE-0405.
```

– Interpolation Method: When the Earth is not the center of motion, the ephemerides of the planets, satellites, asteroids, and/or comets (including associated constants) consistent with the ephemeris file is to be identified so that the recipient can, in a consistent manner, make computations involving other centers:

```
COMMENT Interpolation Method: Created using small-body ephemeris file for 1 Ceres
COMMENT (SB-A1-23).  Based on latest orbit solution which includes observations
COMMENT through 2000-May-15; relative to planetary ephemeris DE-0405.
```

4.6 EPHEMERIS DATA

4.6.1 For Ephemeris Messages, each set of ephemeris data, including the time tag, must be provided on a single line. The order in which data items are given is fixed: (**Epoch**, **X, Y, Z**, (**X_DOT, Y_DOT, Z_DOT**. Units for position (**X, Y, Z**) and velocity (**X_DOT, Y_DOT, Z_DOT**) components at the given epoch are in km and km/s, respectively.

4.6.2 The comma character (,) must be used to delimit these seven items. Commas are not allowed in ephemeris record time tags.

4.6.3 The allowable time formats are the same as those for the metadata keywords `START_TIME` and `STOP_TIME`.

4.6.4 For ephemeris data records, white space within a line is ignored except for within time tags. White space is not allowed within (inside any of) the six numbers making up the state vector.

4.6.5 Within a given block of ephemeris data (all data occurring between two metadata blocks) time must be increasing. Time step size may vary. Duplicate time tags are not allowed.

4.6.6 The occurrence of a second (or greater) metadata block after some ephemeris data indicates that interpolation using ephemeris data occurring prior to that metadata block is not to be done. This method can be used for proper modeling of propulsive maneuvers or any other source of a discontinuity such as eclipse entry or exit.

4.7 REQUIRED EPM FIELDS

EPM files have a set of minimum required sections; some can be repeated (see table 4-2).

Table 4-2: EPM File Layout Specifications

Required Fields	1. Header (first non-blank line) 2. Metadata 3. Ephemeris Data
Allowable Repetitions	Sets of metadata and ephemeris data can be repeated. For example, Metadata Ephemeris Data Metadata Ephemeris Data Metadata Ephemeris Data, …etc.

4.8 CCSDS EPHEMERIS MESSAGE (EPM) EXAMPLE

A simple example of the proposed ephemeris file standard is shown in figure 4-1.

```
CCSDS_EPHEM_VERS = 1.0

META_START
OBJECT_NAME = Mars Global Surveyor
CENTER_NAME = Mars Barycenter
REF_FRAME = EME 2000
TIME_SCALE = UTC
START_TIME = 1996-12-18T12:00:00
STOP_TIME = 1996-12-28T21:28:00.0000
META_STOP

COMMENT  This file was produced by M.R. Somebody, MSOO NAV/JPL, 2000 OCT 11. It is
COMMENT  to be used for DSN scheduling purposes only.
COMMENT  Interpolation Method: Hermite, degree 7.

1996-12-18T12:00:00, 2789.619,-280.045,-1746.755, 4.733702,-2.495860,-1.041956
1996-12-18T12:02:00, 2783.419,-308.143,-1877.071, 5.186043,-2.421245,-1.996084
1996-12-18T12:04:00, 2776.033,-336.859,-2008.682, 5.636786,-2.339517,-1.946873

META_START
OBJECT_NAME = Mars Global Surveyor
CENTER_NAME = Mars Barycenter
REF_FRAME = EME 2000
TIME_SCALE = UTC
START_TIME = 1996-12-28T22:00:00
STOP_TIME = 1996-12-30T01:28:00.0000
META_STOP

COMMENT  This block begins after the spacecraft occultation from 21:28 to 21:58 is over.

1996-12-28T22:00:00, -2432.166,-063.042,1742.754, 7.33702,-3.495867,-1.041945
1996-12-28T22:01:00, -2445.234,-878.141,1873.073, 1.86043,-3.421256,-0.996366
1996-12-28T22:02:00, -2458.079,-683.858,2007.684, 6.36786,-3.339563,-0.946654
```

Figure 4-1: EPM Example

ANNEX A

RATIONALE FOR ORBIT DATA MESSAGES

(This annex is **not** part of the Recommendation)

A1 GENERAL

This annex presents the rationale behind the design of each message. It may help the application engineer to select a suitable message.

A specification of requirements agreed to by all parties is essential to focus design and to ensure the product meets the needs of the Member Agencies. There are many ways of organizing requirements, but the categorization of requirements is not as important as the agreement to a sufficiently comprehensive set. In this section the requirements are organized into three categories:

Primary Requirements - These are the most elementary and necessary requirements. They would exist no matter the context in which the CCSDS P1J is operating: i.e., regardless of pre-existing conditions within the CCSDS or its Member Agencies.

Heritage Requirements - These are additional requirements that derive from pre-existing Member Agency requirements, conditions or needs. Ultimately these carry the same weight as the Primary Requirements. This Recommendation reflects heritage requirements pertaining to some of the panels' home institutions collected during the preparation of the Recommendation; it does not speculate on heritage requirements that could arise from other Member Agencies. Corrections and/or additions to these requirements are expected during future updates.

Desirable Characteristics - These are not requirements, but they are felt to be important or useful features of the Recommendation.

A2 PRIMARY REQUIREMENTS ACCEPTED BY THE ORBIT DATA CODES

Table A-1: Primary Requirements

Requirement	Accepted for OPM?	Accepted for EPM?
Data must be provided in digital form (computer file).	Y	Y
The file specification must not require of the receiving Agency the separate application of, or modeling of, spacecraft dynamics or gravitational force models, or integration or propagation.	N	Y
The interface must facilitate the receiver of the message to generate a six-component Cartesian state vector (position and velocity) at any required epoch.	Y	Y
State vector information must be provided in a reference frame that is clearly identified and unambiguous.	Y	Y
Identification of the object and the center(s) of motion must be clearly identified and unambiguous.	Y	Y
Time measurements (time stamps, or epochs) must be provided in a commonly used, clearly specified systems.	Y	Y
The time bounds of the ephemeris must be unambiguously specified.	N/A	Y
The standard must provide for clear specification of units of measure.	Y	Y
Files must be readily ported between and useable within ‘all’ computational environments in use by Member Agencies.	Y	Y
Files must have means of being uniquely identified and clearly annotated. The file name alone is considered insufficient for this purpose.	Y	Y
File name syntax and length must not violate computer constraints for those computing environments in use by Member Agencies.	Y	Y

Table A-2: Heritage Requirements

Requirement	Accepted for OPM?	Accepted for EPM?
JPL/DSN - Ephemeris data is reliably convertible into the SPICE SPK format using a standard, multi-mission, unsupervised pipeline process. (There will no longer be a team available to oversee and contribute to the preparation of ephemeris information for use by the DSN.). A complete ephemeris, not subject to integration or propagation by the customer, must be provided.	N	Y
JPL/DSN - Ephemeris data provided for DSN scheduling or operations (metric predicts) is to be certified by the providing Agency as correct and complete for the intended purpose. The receiving Agency cannot provide evaluation, trajectory propagation or other usability services.	N	Y
DLR, ESOC - The standard is – or includes – an ASCII format.	Y	Y
DLR, ESOC - The standard does not require software supplied by other agencies.	Y	Y

Table A-3: Desirable Characteristics

Requirement	Accepted for OPM?	Accepted for EPM?
The standard applies to non-traditional objects, such as landers, rovers, balloons, and natural bodies (asteroids, comets).	N	Y
The standard allows state vectors to be provided in other than the traditional J2000 inertial reference frame; one example is the IAU Mars body-fixed frame. (In such a case, provision or ready availability of supplemental information needed to transform data into a standard frame must be arranged.)	Y	Y
The standard is extensible with no disruption to existing users/uses.	Y	Y
The standard is consistent with, and ideally a part of, ephemeris products and processes used for other space science purposes.	N	N
The standard is as consistent as reasonable with any related CCSDS ephemeris standards used for earth-to-spacecraft or spacecraft-to-spacecraft applications.	Y	Y

A3 APPLICABILITY OF CRITERIA TO CODE OPTIONS

The selection of one particular code will depend on the optimization criteria in the given application. Table A-4 compares the two Recommended codes in terms of the relevant selection criteria identified by the CCSDS:

Table A-4: Applicability of the Criteria to Orbit Data Codes

Criteria	Definition	Applicable to OPM?	Applicable to EPM?
Modeling Fidelity	Permits modeling of any dynamic perturbation to the trajectory.	N	Y
Human Readability	Provides easily readable code corresponding to widely used orbit representation.	Y	Y
Remote Body Extensibility	Permits use for assets on remote solar system bodies.	Y	Y
Lander/Rover Compatibility	Permits exchange of non-orbit trajectories.	N	Y

A4 SERVICES RELATED TO THE DIFFERENT ORBIT DATA CODE FORMATS

The different orbit data codes have been distinguished by the self-interpretability of the codes. Both orbit data codes provide for recognizing the boundaries of the orbit data code field and thus can transfer that field, as a block, to another location. The different services that can be achieved without special arrangements between users of the CCSDS orbit data codes are listed in table A-5.

Table A-5: Services Available with Orbit Data Codes

Service	Definition	Applicable to OPM?	Applicable to EPM?
Absolute Orbit Interpretation	State availability at specific times for use in additional computations (geometry, event detection, etc.).	Y	Y
Relative Orbit Interpretation	Trajectory comparison and differencing for events based on the same time source.	Only at time specified at Epoch	Y

A5 DISCUSSION OF RECOMMENDED MESSAGES

A5.1 GENERAL

All the Recommended orbit data messages are ASCII. While binary-based orbit data message formats are computer efficient and minimize overhead on uplinked/downlinked data streams, there are ground-segment applications for which an ASCII character-based message is more appropriate. For example, when files or data objects are created using text editors or word processors, ASCII character-based orbit data format representations are necessary. They are also useful in transferring text files between heterogeneous computing systems, because the ASCII character set is nearly universally used and is interpretable by all popular systems. In addition, direct human-readable dumps of text files or objects to displays or printers are possible without preprocessing. The penalty for this convenience is inefficiency.

A5.2 ORBIT PARAMETER MESSAGE (OPM)

The Orbit Parameter Message code is suited to inter-Agency exchanges which (1) involve automated interaction and/or (2) involve human interaction and (3) do not require high-fidelity dynamic modeling.

The code allows for modeling of any number of maneuvers (as both finite and instantaneous events) and simple modeling of solar radiation pressure and atmospheric drag. The attributes of this code make it also suitable for applications such as exchanges by FAX or voice or applications where the message is to be frequently interpreted by humans. OPMs require the use of an orbit propagator at the receiver's site leading to a higher effort of S/W implementation than for the EPM.

A5.3 EPHEMERIS MESSAGE (EPM)

The Ephemeris Message code is particularly suited to applications that (1) involve automated interaction and (2) require high-fidelity dynamic modeling.

The code allows for any dynamic modeling of any number of gravitational and non-gravitational accelerations. The attributes of this code make it suitable for applications such as exchanges by TCP/IP. The ephemeris message is particularly suitable for use in computer-to-computer communication where frequent, fast automated time interpretation and processing is required, and where high precision is needed.

ANNEX B

GLOSSARY OF SELECTED ORBIT DATA TERMS

(This annex is **not** part of the Recommendation)

B1 PURPOSE

This annex presents definitions of a number of orbit data–related terms used in the Recommendation or useful in understanding the text of the Recommendation.

The definitions used in this CCSDS Recommendation are those approved by the CCIR and are found in various CCIR publications (reference [3] - Report 730). Where appropriate, this Recommendation uses definitions supplied by BIH or CCIR (Study Group 7).

B2 TERMS

ACCURACY:

Generally equivalent to systematic uncertainty of a measured value (reference [3] - Report 730).

ASCII:

A coded set of alphanumeric and control characters used for information interchange. The coded character set used to form the ASCII orbit data messages defined in section 3 is described in detail in International Standard ISO 8859-1 (reference [4]).

COORDINATED UNIVERSAL TIME (UTC): (See Universal Time)

EPOCH:

The origin (the beginning) of a time scale.

INTERNATIONAL ATOMIC TIME (TAI): (See Universal Time)

PRECISION:

Random uncertainty of a measured value, expressed by the standard deviation or by a multiple of the standard deviation (reference [3] - Report 730).

UNIVERSAL TIME (UT) (reference [3] - Recommendation 460-3 - Annex 1):

In applications in which an imprecision of a few hundredths of a second cannot be tolerated, it is necessary to specify the form of UT that should be used:

UT0: the mean solar time of the prime meridian obtained from direct astronomical observation.

UT1: UT0 corrected for the effects of the Earth's polar motion; it corresponds directly with the angular position of the Earth around its axis of diurnal rotation.

UT2: UT1 corrected empirically for the effects of a small seasonal fluctuation in the rate of rotation of the Earth.

TAI: the international reference scale of atomic time (TAI), based on the second of the International System of Units (SI), as realized at sea level, and is formed by the Bureau International de l'Heure (BIH) on the basis of clock data supplied by cooperating establishments. It is in the form of a continuous scale, e.g., in days, hours, minutes and seconds from the origin 1958 January 1 (adopted by the CGPM 1971).

UTC: the time scale maintained by the BIH which forms the basis of a coordinated dissemination of standard frequencies and time signals. It corresponds exactly in rate with TAI but differs from it by an integral number of seconds.

The UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap seconds) to ensure approximate agreement with UT1.

Concise definitions of the above terms and the concepts involved are available in the glossary of the annual publication: *The Astronomical Almanac* (U.S. Government Printing Office, Washington D.C. and H.M. Stationery Office - London).